



## Analysis of Advanced Respiratory Support on board the International Space Station and Commercial Crew Vehicles

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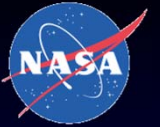
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*<sup>3</sup>NASA Johnson Space Center*

# Introduction

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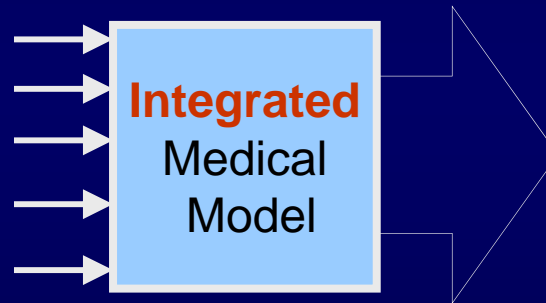
- NASA is collaborating with private entities for the development of commercial space vehicles.
- Space and Clinical Operations Division **was** tasked to review the oxygen and respiratory support systems and recommend what capabilities, if any, the vehicle should have to support the return of an ill or injured crewmember.
- The Integrated Medical Model (IMM) was used as a data source for the development of these recommendations.

# IMM Conceptual Model



## Inputs

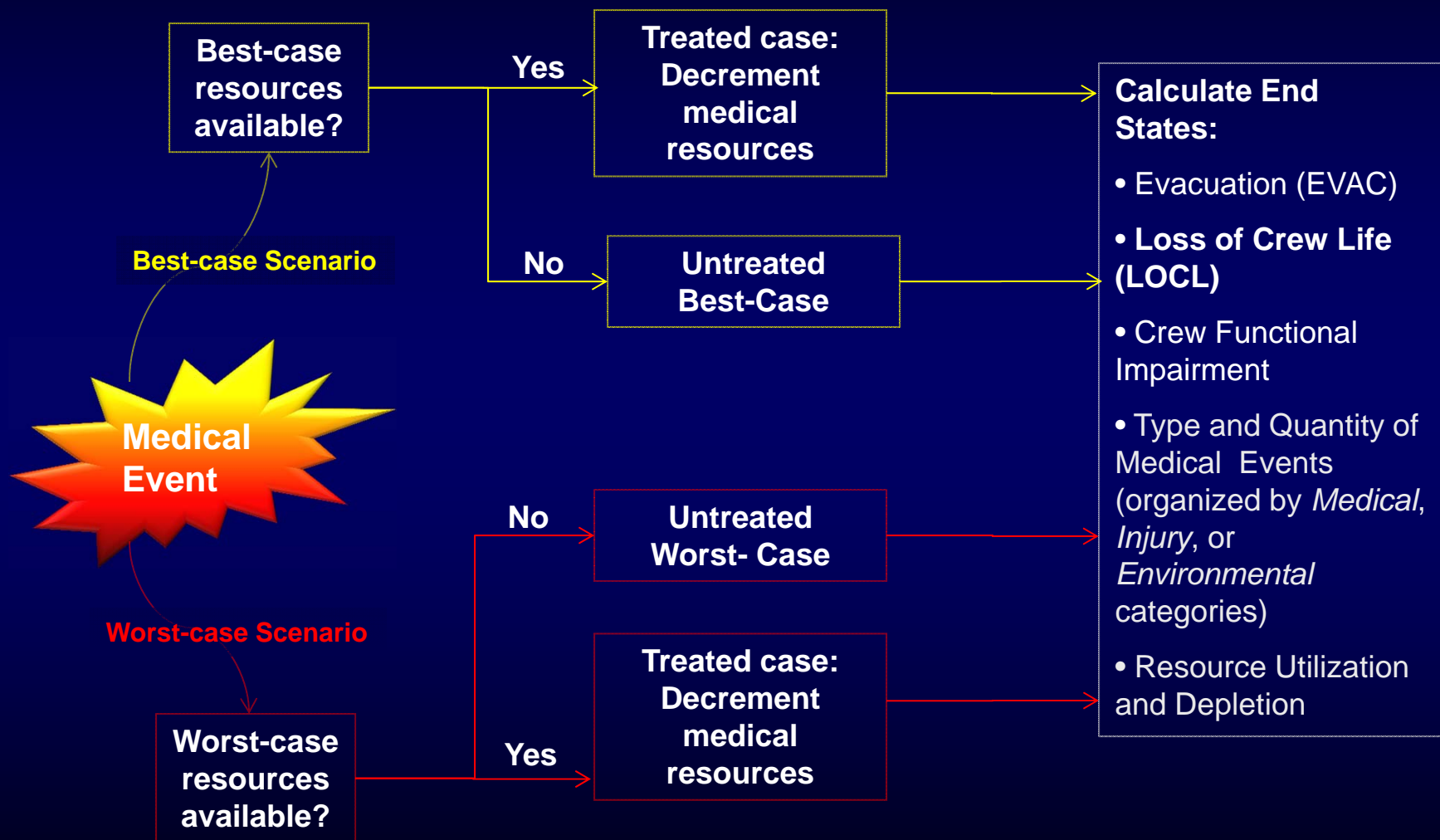
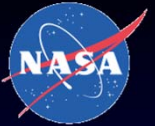
- Medical Conditions & Incidence Data
- Crew Profile
- Mission Profile & Constraints
- Potential Crew Impairments
- Potential Mission End States
- In-flight Medical Resources



## Outputs

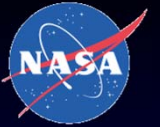
- Medical Condition Occurrences
- Crew Impairments
- Clinical End States
- Mission End States
- Resource Utilization
- Optimized Medical System

# IMM Logic - Event Sequence Diagram



# Methods

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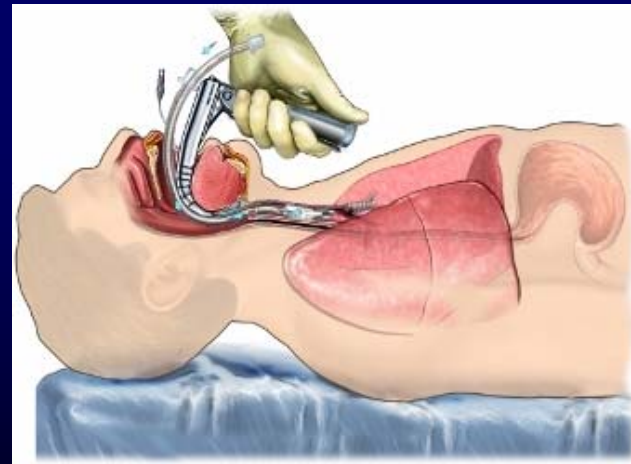
- A collaborative team was formed between the research and operations division to evaluate clinical options.
- The Integrated Medical Model (IMM) was used to simulate a 6-month, 6 crew, International Space Station (ISS) mission.
- Three medical system scenarios were considered based on the availability of:
  - (1) oxygen only
  - (2) oxygen and a ventilator
  - (3) neither oxygen nor ventilator

*Data based on IMM Service Request “Ventilator/oxygen Quantitative Risk Analysis”  
– June 2013*

# Methods



- What is the impact of the presence or absence of oxygen and/or a ventilator for a 6 month, 6 crew ISS mission?



# Present Operations



	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation
ISS	Yes	Yes	No
Soyuz	No	No	No

# Array of Future Options



## Present Operations

	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation	Comments
ISS Presently	Yes	Yes	No	
Soyuz Presently	No	No	No	

## Proposed ISS Options

	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation	Comments
ISS Option 1	Yes	No	No	High flow O <sub>2</sub> only
ISS Option 2	Yes	Yes	No	Same as ISS presently AND we fix resource gaps (fluids, medication). This is for physician crew only.
ISS Option 3	Yes	Yes	Yes	Same as Option #2 AND add extubation (fluids, meds, end tidal CO <sub>2</sub> ). This is for physician crew only.
ISS Option 4	Yes	Yes	Yes	Same as Option #3 AND add crew training. This is for all crewmembers.



# Array of Future Options



## Present Operations

	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation	Comments
ISS Presently	Yes	Yes	No	
Soyuz Presently	No	No	No	

## Proposed ISS Options

	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation	Comments
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ISS Option 4	Yes	Yes	Yes	Same as Option #3 AND add crew training. This is for all crewmembers.

## Proposed CCV Options

	High Flow O <sub>2</sub>	Ventilator (Intubation)	Extubation	Comments
CCV Option 1	No	No	No	Vehicle has nothing.
CCV Option 2	Yes	No	No	Vehicle has high flow O <sub>2</sub> only.
CCV Option 3	Yes	Yes	No	Vehicle has high flow O <sub>2</sub> AND ventilator (N.B. ventilator is from ISS and will not be new hardware)

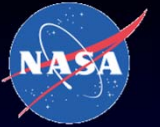
# Results of IMM Analysis

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- Provided probability estimates of medical events that would require either oxygen or ventilator support.
- Provided estimates of crew health, the probability of evacuation, and the probability of loss of crew life secondary to medical events for each of the three medical system scenarios.
- IMM outputs were used as objective data to enable evidence-based decisions regarding oxygen and respiratory support system requirements for commercial crew vehicles.

# Risk Assessment



Outcome	Ventilator and Oxygen	Oxygen	No Oxygen or Ventilator
CHI (%)	90.56	90.44	90.45
EVAC (%)	12.0	12.7	12.9
LOCL (%)	0.59	1.22	1.39

CHI = Crew Health Index (mean); EVAC = Evacuation (mean);  
LOCL = Loss of Crew Life (mean)

## Assumptions and Limitations

1. Based on a 6 month ISS mission with 6 crew with current ISS Medical System.
2. No partial treatment functionality (if oxygen or ventilator is not available, the medical condition is considered to be completely untreated).
3. All medical conditions are correctly diagnosed and all treatments are effective (the use of oxygen and the ventilator will be effective in treating the medical condition).

# Risk Assessment



Outcome	Ventilator and Oxygen	Oxygen	No Oxygen or Ventilator
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CHI = Crew Health Index (mean); EVAC = Evacuation (mean);  
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## Conclusions

1. The unavailability of oxygen and a ventilator has no significant impact on CHI or EVAC.
2. The unavailability of oxygen and a ventilator results in an increased probability of LOCL.
3. Current IMM assumptions and limitations lead to a conservative estimate of the impact of the unavailability of oxygen and a ventilator on crew health and mission outcomes.

# Conclusion

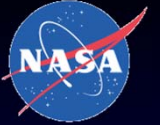
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The Integrated Medical Model provides data that may be used to support informed decisions regarding the development of medical systems for commercial crew vehicles.

# Questions

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Thank You

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# Back-up Slides

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# Integrated Medical Model (IMM)

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- IMM Background
  - Software model used to simulate manned space flight missions
  - Simulates medical events during space flight missions
  - Estimates the impact of these medical events on crew health and mission success
  - Outputs include estimates of crew health, probability of medical evacuation, and probability of medical loss of crew life
  - Optimization routines can be used to design medical systems which maximize crew health and probability of mission success



# Life Before IMM

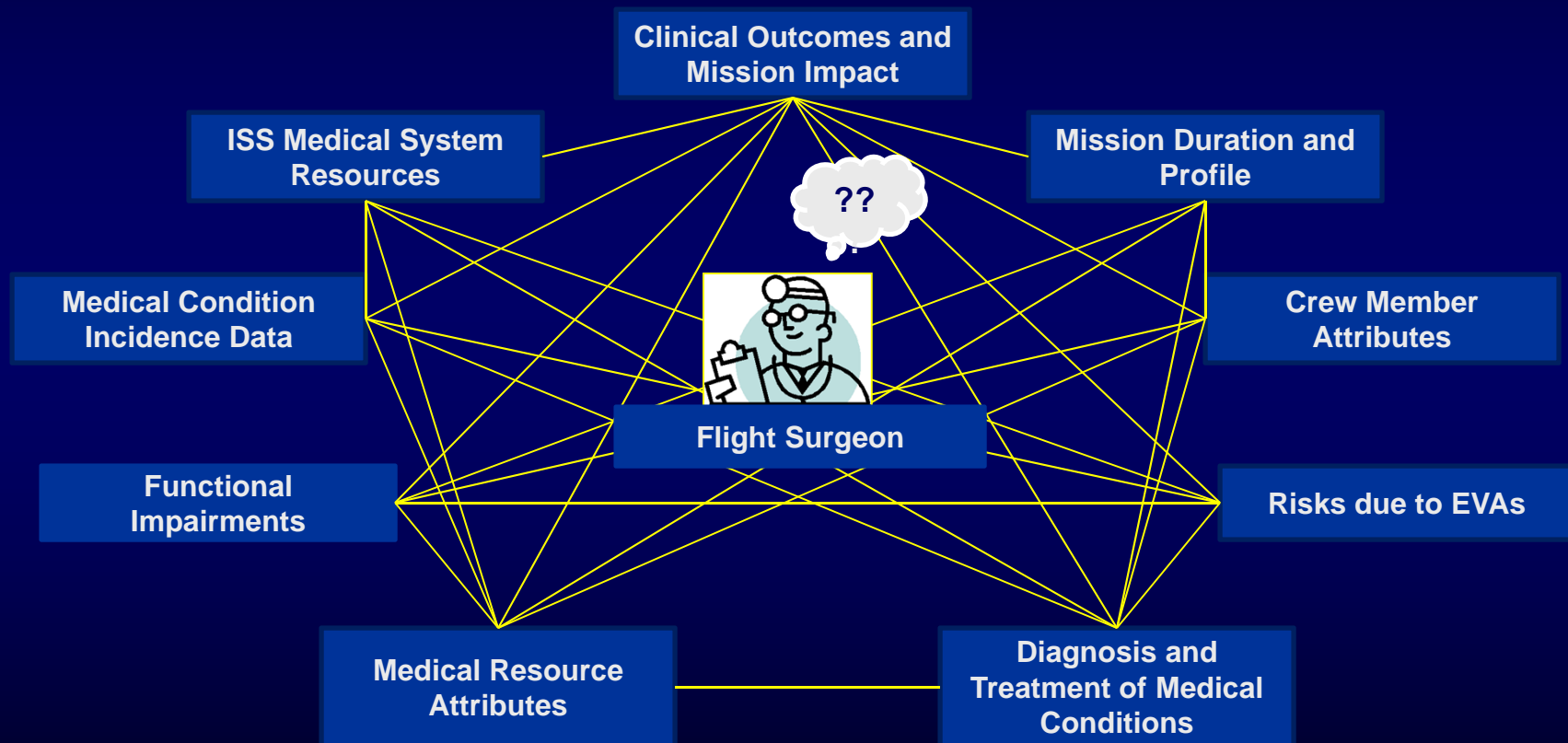


What is the likelihood of a medical evacuation?

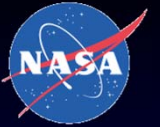
What is the risk of Loss of Crew Life due to illness on ISS?

What medical devices should we have on ISS?

What should be in the Exploration Medical Kit?



# Life Now with IMM



## Mission Specific Inputs

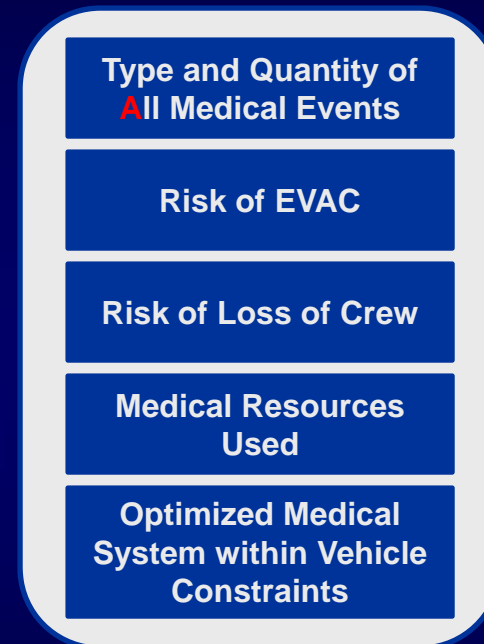


## Monte Carlo Simulations



13,500+ data elements

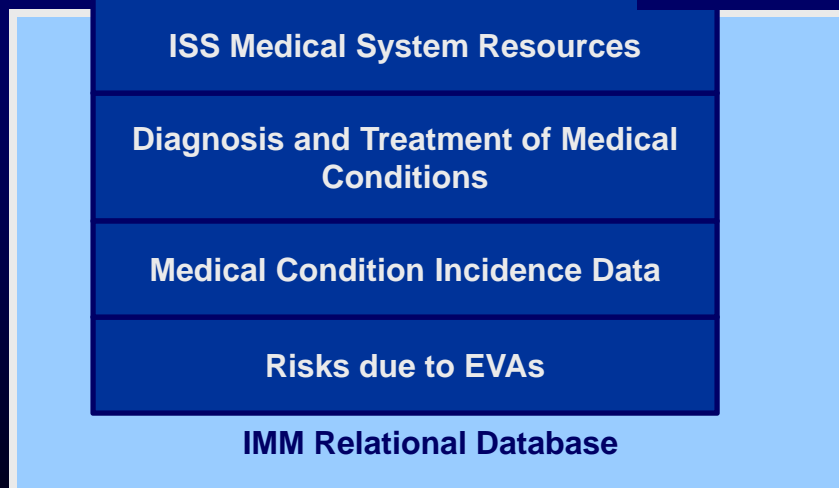
## Quantified Outputs



## Informed Analysis



Flight Surgeon





# Medical Conditions in IMM by Category

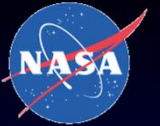
## Injury/Trauma

Acute Compartment Syndrome  
Abdominal Injury  
Back Injury  
Chest Injury/Pneumothorax  
Dental Tooth Avulsion  
Eye Abrasion  
Eye Penetration  
Elbow Dislocation  
Finger Dislocation  
Fingernail Delamination (EVA)  
Head Injury (TBI)  
Hip/Proximal Femur Fracture  
Hypovolemic Shock  
Lower Extremity Stress Fracture  
Lumbar Spine Fracture  
Neck Injury  
Neurogenic Shock  
Paresthesias/Hot Spots (EVA)  
Shoulder Dislocation

## Environmental

Acute Radiation Sickness  
Altitude Sickness  
Barotrauma (ear/sinus block)  
Burns  
Decompression Sickness (EVA)  
Eye Chemical Burn  
Headache (CO<sub>2</sub> induced)  
Smoke Inhalation  
Toxic Exposure

# Medical Conditions by Category



## Medical Illness

Abnormal Uterine Bleeding

Acute Arthritis

Acute Prostatitis

Allergic Reaction

Anaphylaxis

Angina

Anxiety

Appendicitis

Afib/Aflutter

Back Pain (SAS)

Behavioral Emergency

Biliary Colic

Cardiogenic Shock

Choking

Constipation (SAS)

Dental Abscess

Dental Avulsion

Dental Caries

Urinary Tract Infection

Urinary Retention

Dental Crown Replacement

Dental Exposed Pulp

Dental Filling Replacement

Depression

Diarrhea

Eye Corneal Ulcer

Eye Infection

Gastroenteritis

Acute Glaucoma

Headache (late)

Headache (SAS)

Hemorrhoids

Hypertension

Indigestion

Influenza

Insomnia (SAS)

Insomnia (late)

Kidney Stone

Vaginal Yeast Infection

Visual Impairment (VIIP)

Medication Overdose

Mouth Ulcer

Nasal Congestion (SAS)

Nosebleed (SAS)

Otitis Externa

Otitis Media

Pharyngitis

Respiratory Infection

Shingles

Seizures

Sepsis

Sinusitis

Skin Infection

Skin Rash

SMS (SAS)

Stroke

Sudden Cardiac Arrest

Urinary Incontinence

JMK6 Urinary Retention

SAS = Space Adaptation Syndrome

## Slide 20

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JMK6

Duplicate (also at top of 2nd column)

JKrauchs, 4/29/2014

# IMM Team

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- Douglas Butler, MBA – Project Manager
- Eric Kerstman, MD, MPH – Clinical Lead
- Millennia Foy, PhD – Lead Modeler/Epidemiologist
- Marlei Walton, PhD – Project Scientist
- Lynn Saile, RN, MS - Clinical Informatics Lead
- Lynn Boley, RN, MSN - Clinical Researcher
- Ronak Shah, DO, MPH – Medical Reviewer
- Alexander Keenan, MS - Modeler
- Jerry Myers, PhD – External Module Lead